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Results of Earth Observation Study on STS-31 For Terra Geode

TEC

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May 1992

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Terra Geode is a MMIS experiment developed by the U.S. Army Engineer School. The experiment is designed to evaluate the utility of a trained military space-based observer providing information for tactical movement. The experiment is being done in four phases, (1) military astronaut observations, (2) geologist-astronaut observations, (3) military payload specialist observations, and (4) permanent manned presence in space. Phase I consisted of the planning stages and informal discussions with military astronauts who had been asked to observe certain geologist features. It was determined that further investigations were warranted for future phases. A geologist-astronaut flying on STS-31 agreed to conduct Phase II on a time available basis. The flight of STS-31 was 5 days long, from 24 April to 1 May 1990. Many data points were observed during STS-31's high altitude, short duration flight. It was determined that it is feasible to identify and record the various elements that comprise a mobility prediction, and to explore the degree of accuracies that can reasonably be expected from a trained observer in orbit.

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CONTENTS

	PAGE
LIST OF FIGURES	v
PREFACE	vi
INTRODUCTION	1
DISCUSSION	2
Target Folders	2
Evaluation	4
Discussion	4
Soil Color Studies	4
Development	4
Evaluation	6
Discussion	9
Ground Mobility Checklist and Observations	9
Development	9
Developing of the Ground Target Observation Schedule	10
Ground Target Checklist Development	10
Evaluation	10
Required Skills	14
Techniques	14
Vegetation Analysis	18
Soils	18
Hydrology	18
Obstacle Determination	19

CONTENTS (Continued)

	PAGE
Ground Mobility Checklist and Observations (Continued)	
Cross Country Mobility Determination	19
Discussion	19
Observation	20
CONCLUSION	20

FIGURES

FIGURE	TITLE	PAGE
1	Target Site Listing	3
2	Proposed Target Folder	5
3	Soil Color Comparisons	7
4	Sample Orbital Traces for STS-31	11
5	Earth Observation Chart	12
6	Earth Observation Checklist	13
7	Ground Target Observation Opportunities	15
8	Ground Target View Opportunities	17

PREFACE

This experiment was conducted under the U.S. Army Engineer School Military Man in Space experiment: Terra Geode. The experiment was conducted during the flight of STS-31 between 24 April to 1 May 1990. The results of the experiment were obtained during a debriefing session held 7-8 May 1990 at Johnson Space Center. The planning, execution, and evaluation was conducted under the supervision of CPT John Karpiscak III, Topography/Space Branch, Material/Logistics Systems Division, Directorate of Combat Developments.

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RESULTS OF EARTH OBSERVATION STUDY ON STS-31 FOR TERRA GEODE

INTRODUCTION

Terra Geode is a Military Man in Space experiment developed by the U.S. Army Engineer School at Fort Leonard Wood, Missouri. The experiment is designed to evaluate the utility of a trained military space-based observer making ground mobility predictions for tactical movement. The space-based observer will assess an area of interest to a ground commander from orbit, record and then report his findings to that commander, and influence the outcome of military operations.

The experiment is divided into four phases: military astronaut observations (Phase I), geologist-astronaut observations (Phase II), military payload specialist observations (Phase III), and finally, a permanent manned presence in space (Phase IV).

Phase I consisted of informal discussions with military astronauts who had been asked to observe certain geological features. It was determined that further investigations were warranted and Phased II through IV were planned. The flight of the experiment on STS-31 was a significant step forward in developing the final form of Terra Geode. With Phase I observations concluded, the Army Engineer School was seeking an opportunity to fly Phase II. They learned that Dr. Kathryn Sullivan, NASA's only geologist-astronaut, was about to make her second space flight as a member of the STS-31 crew and would serve as a mission specialist. At the request of the U.S. Army Space Command and the U.S. Army Engineer School, she agreed to conduct Phase II of the experiment informally, on a time available basis. Phase II would serve two purposes: (1) to get a trained geologist's perspective on what could be observed from orbit, and (2) to develop Earth observation techniques which would serve as a basis from which to develop the final form of the experiment incorporating trained military observers (Phases III and IV).

The flight of STS-31 was 5 days long, from 24 April to 1 May 1990. Debriefing following the flight was conducted at Johnson Space Center on 7-8 MAY 90. Representatives from the Engineer School, CPT John Karpiscak (Directorate of Combat Developments) and SFC Thomas Schroder (Directorate of Topographic Engineering) participated in debriefing Dr. Sullivan. LTC Gary Kratochvil, U.S. Army Space Command, was also present for a portion of the debriefing.

In Phase II, moderate success was achieved. Dr. Sullivan gave the impression that given the constraints of the first iteration of this experiment, the experiment was feasible. Due to the informal nature of the experiment, and to her commitments to ensuring the deployment of the primary payload, all aspects of the experiment were not completed. Many data points were observed during STS-31's high altitude, short duration flight. These will better define the capabilities of human observer in orbit. Dr. Sullivan was unable to provide mobility predictions for any of the sites she observed. However, during the flight she was able to determine the feasibility of identifying and then recording the various elements that comprise a mobility prediction, and to explore the degree of accuracies that can reasonably be expected from a trained observer in orbit.

DISCUSSION

The Phase II experiment, as flown aboard STS-31, was designed to evaluate specific earth observation techniques, make mobility predictions, and determine the feasibility of measuring certain geomorphologic features from space.

The experiment consisted of a series of target folders from 38 geological and climatically dissimilar areas, a commercial soil color chart, and a ground mobility checklist that was developed for the flight. Due to the limited time available to prepare the experiment prior to launch and the latitudes that the space shuttle would pass over, ground truth would be available for only four sites: Fort Hood, Texas; Fort Huachuca, Arizona; Hawaii Training Center, Hawaii; and the Northwest Cape Joint Facility, Exmouth, Australia. Launch, operational and orbital constraints limited Earth observation to a region between 28.5 degrees North and 28.5 degrees latitude. The view would be from an extremely high altitude; 310 nautical miles, the highest yet flown by a space shuttle, virtually double a shuttle's normal operating altitude. Further, Earth observation opportunities were confined to the last two flight days due to primary payload commitments by Dr. Sullivan.

TARGET FOLDERS

Development. Ground target selection was based on several factors:

1. variety of terrain.
2. ease of identification.
3. limitations due to the orbital inclination of the vehicle.
4. availability of ground truth data.
5. adequate photograph and map coverage.
6. the possibility of site obscuration by weather.
7. the shuttle's launch window.

To protect against the possibility of all the target sites being obscured by weather, a total of 38 sites were developed. These sites were distributed across the world between 28.5° north and 28.5° south latitude. In addition to solving the weather outage problem, scattering the sites also solved the problem of losing observation opportunities due to changes in the actual time of launch. Delays in launch would change the time of target overflight, and thus the sun angles at each site would change. If the launch time was delayed, observation opportunities could radically vary. If the launch was delayed a few hours, ground targets that would have otherwise been in full sunlight during the flight might now be in twilight, others might be in total darkness. Thus, ground targets were distributed worldwide to ensure the probability that at least a few of the selected ground targets would be observed.

Folders for each target consisted of a series of increasing scale maps followed by a photograph of the site designed to 'walk' the astronaut down to each site. Each folder had a hemispheric map followed by a 1:1,000,000 Operational Navigation Chart (ONC), a 1: 500,000 Tactical Pilotage Chart (TPC), a photograph or LANDSAT image of the target area, and a series of site-specific questions for the astronaut to comment on (a listing of the target sites can be found in figure 1). Target sites were designated on both the photographs and TPCs by a red border. This allowed Dr. Sullivan to orient herself to the scale of the target, and the approximate ground colors

Latitudes and longitudes represent the centers of mass of each ground target.

TGT NO	LAT	LON	LOCATION	AREA OF STUDY
01	25 56N	100 51W	Mexico	Monterrey
02	30 16N	115 22W	Mexico	Baja Peninsula
03	25 55N	059 49E	Iran	Southern Coastline
04	22 57N	082 54W	Cuba	Cienfuegos
05	22 55N	059 02E	Oman	Desert
06	17 28N	049 04E	PDR of Yemen	Desert
07	20 05N	075 20W	Cuba	Guantanamo
08	14 22S	074 44W	Peru	Coastal Region
09	18 35S	070 11W	Chile	Tacna
10	25 51S	015 36E	Namibia	Namib Desert
11	18 36S	013 17E	Namibia	Namib Desert
12	17 56S	024 55E	Botsw./Namibia	Desert
13	23 06S	024 54E	Botswanna	Kalahari Desert
14	21 54N	017 09E	Chad	Libyan Desert
15	13 09N	013 54W	Senegal/Gambia	Marsh Region
16	22 51N	024 33E	Libya/Egypt	Desert
17	21 31N	011 38W	Mauritania	Dunes D' Alafia
18	*** Deleted ***			
19	23 50S	017 50E	Namibia	Kalahari Desert
20	05 50S	029 15E	Zaire	Plains
21	01 24S	036 01E	Kenya/Tanzania	Serengeti Plain
22	01 28N	036 40E	Kenya/Tanzania	Serengeti Plain
23	07 20N	037 59E	Ethiopia	River Valley
24	02 59N	072 02W	Columbia	Jungle
25	*** Deleted ***			
26	11 38N	085 59W	Nicaragua	Volcanic Coastline
27	28 47N	105 43W	Mexico	Chihuahua
28	23 30N	034 00E	Egypt	East of Aswan
29	11 38N	005 59W	Mali	Lowlands
30	21 47N	055 53E	Saudia Arabia	Umm as Samim
31	27 00S	021 00E	South Africa	Desert River
32	*** Deleted ***			
33	*** Deleted ***			
34	31 15N	097 45W	USA	Fort Hood, Texas
35	31 30N	110 30W	USA	Fort Huachuca, Arizona
36	19 40N	155 49W	USA	Army Tng. Facil., HA
37	21 50S	123 40E	Australia	Simpson Desert
38	21 53S	114 08E	Australia	NW Cape Jt. Facility

Figure 1. Target Site Listing.

and to identify terrain features to serve as visual cues for target acquisition. Target sites consisted of areas approximately 130 by 100 kilometers.

Evaluation. Target folders were used exclusively for target orientation and familiarization during the training phase. Notes from each site were made in a small, NASA-produced in flight world atlas that Dr. Sullivan took on board with her. While in orbit, she relied on these personal notes for orientation and for performing specific site observation tasks. Dr. Sullivan noted that the NASA in flight atlas had shortcomings in its levels of detail, and by itself would not have been enough to aid her in orienting herself to the ground targets or in conducting the observations.

During the debriefing, she stated that in order to familiarize an astronaut with a particular target site, a minimum of one oblique photograph and one ONC per site should be made available to train the astronaut properly. She mentioned that oblique photographs (although rare in the NASA film archives) provide the best source for site familiarization to the observer because they provide a perspective that is similar to an astronaut's view from orbit. Also, the oblique photographs provide a better sense of scale of the surrounding terrain to the target area and they indicate which geophysical features an astronaut can use to provide visual cues or guides to lead an observer on to the target site. Providing data such as altitude reference points for a mountain peak will aid the space based observer in scaling nearby geophysical features. Although Dr. Sullivan did not use the ONCs much, she noted that they can serve as a basis of determining scales in the target area. Known dimensions and elevations of nearby features can be used to provide the observer with a readily available scale reference while in orbit. The oblique photographs, coupled with an ONC, will enable future observers to judge relative scales of features and will provide a handy reference within a target area.

A checklist for making terrain evaluations (see ground mobility checklist) was also provided.

Dr. Sullivan also noted that maps and photographs should where possible, have a high degree of correlation. The best method to achieve this correlation is to construct arbitrarily a target site boundary; a box on both the map and the photograph indicating the same area of land to be studied. This aid will help the observer in site familiarization. While nadir, or near nadir, photographs can be used to orient an observer to features within the target area, long oblique shots aid in the observation process by showing terrain features that provide visual cues to guide an observer to a target site.

Discussion. Future ground target folders should consist of an ONC and an oblique photograph of the target site; the greater the oblique view, the better. Target folders should also indicate several readily observable terrain features to serve as visual cues to lead an observer to the target site. Mountains are preferred as they can be scanned for while still on the shuttle's horizon (see figure 2). Linear features within or near the target site should also be noted on the target folder to provide the observer with a better sense of scale and to provide a handy measuring tool within the target site.

SOIL COLOR STUDIES

Development. Soil color studies were also an integral part of the experiment. This was the first attempt by an astronaut to classify a soil type by color from space. A commercially obtained Munsell Soil Color Chart was flown on STS-31. The chart consisted of a series of pages of color chips (1/2 inch by 5/8 inch). The color chips were arranged by chroma, value, and hue for a range of hues that spanned from reddish to greenish components. Directly beneath each chip was a 3/8"

(Insert map here)

VISUAL CUES	OBS OPPORTUNITIES	
	ORBIT	MET/TCA
3 min after Sierra Madre Oriental	60	3/23:13:00
long flat plain prior to target	56	4/00:53:00
mtn SE of Saltillo 10340 ft		
Airstrip NE of Saltillo 4600 ft		
Sierra Madres ahead		orb 60 best sun
		orb 66 last pass

OBJECTIVES	TECHNIQUES
Evaluate earthquake/mudslide effects vic Saltillo for mech ops east and south of city//baseline vegetation//slash-burn	50mm 250mm S of city use polariz eq.

01-Mexico/Monterrey area

Figure 2. Proposed Target Folder.

diameter hole that the observer could use to see through to compare and classify the soil type. The chart served a dual purpose: it not only aided the observer in determining and recording the soil type, but it also provided a reference for the color correction of photographs post-flight.

Dr. Sullivan was asked to make several measurements of the colors of exposed soils during the flight. She was not limited strictly to the target sites, but was free to look for areas of exposed soil. The objectives were to determine the feasibility of correctly identifying soil color from orbit, to develop an appropriate technique for measurement, and to determine at what point during the observation of a target site that color measurements should be conducted. Several different methods were discussed pre-flight with Dr. Sullivan on how to best use the chart to make the measurements on orbit.

Evaluation. During one orbit, Dr. Sullivan was able to evaluate several sites in southwest and southeast Asia. She recorded the values for these soil colors in her flight log using the Munsell Soil Color Chart system provided.

When the data was returned, the search began for reports on soil conditions in the observed areas. Soil surveys for particular regions or countries would typically contain Munsell Soil Color measurements taken in the field. The field measurements could then be compared to the measurements taken in orbit by Dr. Sullivan (comparisons can be found in figure 3). Although many publications on the soil conditions in these areas were reviewed, the needed data could not be located. Most of the publications dealt only with soils suitable for agricultural use or with areas that were far removed from the observed sites.

A good source was eventually located in a 12 volume series, the United Nations Publication, FAO-UNESCO Soil Map of the World. The volumes covered the regions studied by Dr. Sullivan, describing general soil conditions at a scale of 1:5,000,000. Although they covered the appropriated regions, the maps contained several deficiencies.

Because of the small scale, soil types and conditions were described only in general terms. Not all soils identified on the map were described by their physical properties or color value; only the predominant soil types for each region were presented in depth. Each volume did contain some specific soil condition evaluations, which described soil color in detail. However, these were in some instances far removed from the observed sites and were frequently of different soil types.

In no instance was there a perfect correlation between the sites reported in the UNESCO manuals and the sites observed from orbit. Thus, rough analyses were made by taking data from the publication of like-soil conditions and comparing it to what was seen from orbit.

The first site viewed was an area of dune fields located east of the Makran mountain range in southeastern Iran. The dunes were characterized by the astronaut as having a soil color of 5YR 6/6. By comparison, the UNESCO soil map characterizes the region as being mainly composed of Lithosols and Xerosols. The publication cites Haplic Xerosols as being the closest match to the soil type observed and is characterized as being brown to dark brown with a Munsell color value of 10YR 4/3.

The Pakistani lowlands east of the Makran range were judged by Dr. Sullivan to be 10YR 8/3. Regional soils as noted on the UNESCO map are characterized as being composed primarily of

SOIL COLOR SITE 1: DUNE FIELDS EAST OF MAKRAN MOUNTAIN RANGE, EASTERN IRAN

OBSERVED COLOR: **5YR 6/6**

FAO SOIL CHARACTERIZATION: LITHOSOLS, XEROSOLS

CLOSEST PUBLICATION MATCH: HAPLIC XEROSOLS- 10 YR 4/3

SOIL COLOR SITE 2: PAKISTANI LOWLANDS EAST OF THE MAKRAN MOUNTAIN RANGE, PAKISTAN

OBSERVED COLOR: **10YR 8/3**

FAO SOIL CHARACTERIZATION: LITHOSOLS-REGOSOLS, YERMOSOLS

CLOSEST PUBLICATION MATCH: CALCARIC REGOSOLS- 10YR 6/3 (dry)
10YR 5/3 (wet)
HAPLIC YERMOSOLS- 10YR 6/2 (dry)
10yr 4/3 (wet)

SOIL COLOR SITE 3: GANGES DRAINAGE, EASTERN INDIA

OBSERVED COLOR: **10YR 8/3 to 10YR 7/5**

FAO SOIL CHARACTERIZATION: EUTRIC GLEYSOLS

CLOSEST PUBLICATION MATCH: EUTRIC GLEYSOL- 5Y 4/1 (dry)
5Y 5/1 (wet)
EUTRIC CAMISOL- 2.5Y 4/4 (dry)
5Y 6/3 (wet)

SOIL COLOR SITE 4: BURMA/THAI/LAOS BORDER REGION

OBSERVED COLOR: **7.5YR 3/8**

FAO SOIL CHARACTERIZATION: ACRISOLS-FLUVISOLS

CLOSEST PUBLICATION MATCH: ORTHIC ACRISOLS- 10YR 6/4 (dry)
7.5YR 4/4 (wet)
to 7.5YR 6/4 (dry)
7.5YR 4-5/4 (wet)

SOIL COLOR SITE 5: PAPUA-NEW GUINEA RIVER SEDIMENT PLUME, EASTERN NEW GUINEA

OBSERVED COLOR: **10YR 7/4**

FAO SOIL CHARACTERIZATION: PHAEOZEMIC

CLOSEST PUBLICATION MATCH: GLEYIC PHAEOZEM- 10YR 3/3

Figure 3. Soil Color Comparison.

Lithosols-Regosols and Yermosols. Calcaric Regosols are characterized as being pale brown, Munsell color of 10YR 6/3 when dry, changing to a brown 10YR 5/3 when moist. Haplic Yermosols were characterized as being a dark grayish brown, 10YR 6/2 when dry, and a light gray, 10YR 4/2 when moist.

River valley bottoms on the Ganges River in India were observed and determined to be 10YR 8/3 to 10YR 7/5. The UNESCO study characterizes the region as being composed of Eutric Gleysols, having values from 5Y 4/1 dry to 5Y 5/1 moist, and Eutric Camisols, 2.5Y 4/4 dry to 5Y 6/3 moist.

During a pass over extreme northern Thailand, Burma, and Laos, mining excavations were observed to have a color value of 7.5YR 3/8. In this instance, formerly subsurface soils as well as bedrock were now exposed to view. The United Nations soil study indicated soils in this region are primarily composed of Acrisols-Fluvisols. The report cites Orthic Acrisols measured at a site located approximately 60 miles south of the observed area. Subsurface soils in that region, at a depth of 10 to 36 centimeters, were characterized as ranging in value from 7.5 YR 4/4 moist, 10YR 6/4 dry to 7.5YR 4-5/4 moist, 7.5YR 6/4 dry.

A river sediment plume in Papua, New Guinea was the last soil target to be studied. The area was characterized as having a value of 10YR/7/4. The United Nations soil map of the region characterizes the soil as Phaeozemic in nature. The UNESCO study identifies a soil type in the same drainage basin near the observed area as being a Gleyic Phaeozem, a dark brown heavy clay having a value of 10YR 3/3.

Prior to observing soil color values, Dr. Sullivan modified the chart organization in orbit. She found it more advantageous to remove the chart's pages from their commercial binder and reassemble the most likely charts into a continuous palette rather than thumb through the pages. The pages were removed from their 3-ring binder and rearranged into a series of three interconnected pages held together with separate binding rings forming a continuous palette of colors to examine and choose from.

Dr. Sullivan noted during the debriefing that lighting conditions on the orbiter precluded using the small circular openings located beside each hue as would normally be done in the field. Difficulties with continual shifts in the refocusing the eye prevented the obvious technique of the astronaut holding the soil chart close to the eye and then viewing out of the orbiter's overhead windows. The most effective method used was to place the chart at arms length and against the window so that both the chart and window could be viewed with a minimum of eye shift/focus difficulty. The chart also had the added advantage of being lit by the reflected light from earth.

Dr. Sullivan determined that the most appropriate time to make soil color observations was between 60 and 30 degrees from nadir. However, there is a trade-off associated with this. Owing to this viewing angle, the true colors tended to be slightly muted due to back-scattering of light through the atmosphere. This tended to add a blue component to the color being observed, and some shades tended to blend with the blue component. The astronaut also added that the color picture will never be complete until the observer is directly overhead and the back-scattering is minimized. Despite this, she believes that an observer will still be able to obtain a "highly accurate approximation of the soil colors" from the 60 to 30 degree look angle.

Discussion. Based on input from the astronaut and results from the data, one can obtain correct soil color values from space. The next space-based terrain observers need to be extremely fluent with the colors in the chart and they need to make it an integral part of their training. This will reduce the time needed for continual chart referencing and will allow an observer to spend more time in direct view of a ground target.

The format for color chip array will have to be modified from its commercial configuration to something more easily reviewed. The viewing holes in the commercial chart below each color chip on the page were not used as they caused eye shift and focusing problems with the observer. Munsell color chips, placed in a different configuration, appear to be needed. Dr. Sullivan recommended investigating other display methods, which included sawtooth, wheel, or fan configurations for use in orbit next time.

Using colored gels or transparencies was also discussed as an alternative to the color chips. The advantage of the gels would be to eliminate the time required to shift from viewing the target to viewing the color. After some consideration, Dr. Sullivan is unsure that they would be appropriate for determining soil colors because there are some inherent problems associated with the accurate reproducibility of colors.

Comparing her data with the broad categories based on the UNESCO soil maps, Dr. Sullivan was able to determine soil color to within the correct page in three out of five attempts. The color values for the observation were generally within a 2 to 3 color chip range of being the correct assessed value.

Differences between the data taken while in orbit and the UNESCO survey could have several explanations. Problems with establishing ground truth were described previously in the evaluation section. The differences could be due to outcrops of soil viewed and were not representative of the general soils within the region, or as was pointed out, simply over generalization on the part of the UNESCO survey.

Soil color is one of several facets of terrain analysis. It provides clues as to composition and to relative soil moisture content on the surface. These clues in turn can be used to indicate relative drainage and trafficability for ground forces. If soil color is to be studied from space, an index needs to be developed of probable soil types arranged by color composition. More experimentation needs to be done in this area on subsequent space shuttle flights. This may be accomplished my having future astronauts observe soils in areas that have soil color ground truth.

GROUND MOBILITY CHECKLIST AND OBSERVATIONS.

Development. Pre-flight discussions with the astronaut and the ground support personnel, and a review of the flight plan indicated that most favorable observation times came on flight days 4 and 5. Operational commitments with the primary payload and other conditions prevented observation opportunities on earlier flight days.

Even though flight days 4 and 5 were optimal, Dr. Sullivan could not devote a large margin of time waiting for the shuttle to pass a ground target. There were many other scheduled and non-scheduled tasks required to be performed during that time as well. Additionally, because the experiment went aboard un-manifested, the formally scheduled experiments would always have priority. To assist Dr. Sullivan in scheduling ground target observation opportunities in between other tasks, a schedule of observation opportunities was developed indicating the Mission Elapsed Time (MET) that the shuttle was to fly over or near each ground target.

Developing of the Ground Target Observation Schedule. Developing of the schedule was quite an intensive operation. A map of the earth with superimposed ground tracks (paths the shuttle would take as it would fly around the Earth) for STS-31 was obtained from the Earth Observation Office at Johnson Space Center. The map indicated the orbit number for flight days 4 and 5, the width of the earth observable during each pass (as seen with a 50mm lens--in the case of STS-31, about 1 degree either side of the ground track), and the sunlit portion of each orbit (figure 4). The coordinates of each ground target were superimposed over the map and the map was then checked against the Crew Activity Plan (CAP) to determine the Time to Closest Approach (TCA) and the approximate lighting conditions for that area.

As the launch date approached, modifications to the original flight plan allowed Dr. Sullivan more observation opportunities than originally planned. The schedule was converted to chart form and expanded to include observation opportunities from the latter portion of flight day 2 through flight day 4. As a result, opportunities on flight day 5 had to be dropped. In its final form, the chart (see figure 5) indicated the ground target, orbit number, MET, TCA, next, and best opportunities for observation when repeated passes of a site were possible.

Ground Target Checklist Development. Each of the target folders were initially equipped with questions tailored to each specific site. The intent was to determine the extent of the astronauts's ability to resolve particular ground features of interest and the degree of correlation between the observed and mapped ground features. As a part of training for the experiment, the elements that comprise a comprehensive terrain analysis were explained to Dr. Sullivan prior to flight. She expressed concern that individual questions for each site would not be workable. She was also concerned with the possibility that too much observing time would be wasted because of trying to ensure the questions for each site were addressed. During the post-flight debriefing, Dr. Sullivan noted that having four months to study the targets before the mission was sufficient.

During a training session with Dr. Sullivan, a general checklist format was used because it would be more beneficial than having individual questions for each site. The checklist would have to be generalized enough to fit observations of all sites, yet specific enough to encompass all of the elements required to conduct a terrain analysis. A checklist was developed following the basic TTADB format with some modification. The format was reduced in size due to the need to keep the checklist compact and, at astronaut request, to limit it to one page.

The checklist format has distinct advantages over developing questions for individual sites. Developing this checklist would enable Dr. Sullivan to make mental notes in a similar manner for each site. The checklist would also eliminate the problems of carrying and organizing question sheets on orbit for particular sites. The checklist (figure 6) was reduced to a 5 by 7 card to be used over each ground site.

Evaluation. Most of the observations came during flight day four. Of the 38 sites selected for observation, 8 were observed. Although some of the sites were observed in detail, others could receive only a brief amount of attention. due to Dr. Sullivan's previous commitments. Even from an

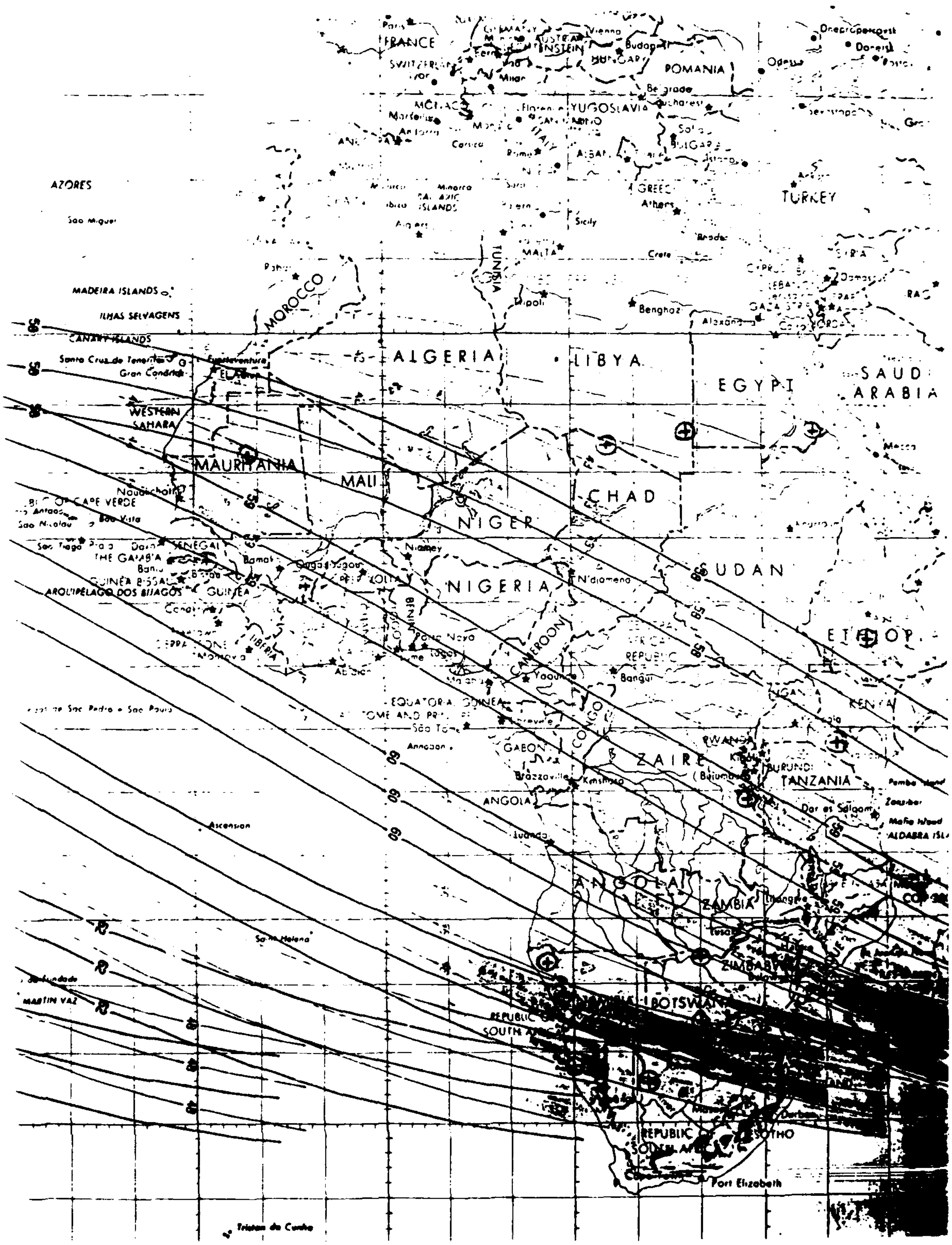

Figure 4. Sample Orbital Traces for STS-31.

TERRA GEODE TARGET OPPORTUNITIES

ORBIT	TCA (MET)	SITE OR AREA	PRI	COLOR	ORBIT # OF NEXT OPP	COMMENTS
42	2/18:17:00	Chad/Libyan Desert	7	YES		Only daylight pass
42	2/18:19:00	Libya/Libyan Desert	1	YES		Only daylight pass
42	2/18:22:00	Egypt/Betw L.Nasser-Red Sea	5	YES		Only daylight pass
42	2/18:25:00	PDR Yemen/Umm as Samim	3	YES		Only daylight pass
42	2/18:40:00	Austrail/NW Cape Joint Facil.	4	NO		Only Daylight pass
42	2/18:45:00	Austrailia/Great Sandy Desert	2	YES		Only daylight pass
42	2/18:47:00	Austrailia/Gibson Desert	6	YES		Only daylight pass
43	2/20:07:00	Ethiopia/River valley	1	NO		Only daylight pass
44	2/21:42:00	Mauritania/Dunes d' Alafia	1	YES	58	
44	2/21:44:00	Zaire/W. of Kalemi	2	NO		
45	2/22:50:00	US/Ft Hood TX- Maneuver areas	1	NO	46,60,61	
46	3/00:33:00	Mexico/Baja cross-peninsula	6	YES	61	
46	3/00:34:00	US/Ft Huachuca-Bisbee pit Mine	2	NO	61	Photo op
46	3/00:35:00	Mexico/Chihuahua	7	NO	47,61	
46	3/00:36:00	US/Ft Hood TX- Maneuver areas	1	NO	60,61	
46	3/01:12:00	Namibia/Coastline-desert	4	YES		Only daylight pass
46	3/01:19:00	Namibia/Namib Desert	3	YES	61	
46	3/01:25:00	Botswanna/Kalahari desert	5	NO		
47	3/02:12:00	Mexico/Baja cross-peninsula	2	NO	61	
47	3/02:16:00	Mexico/Chihuahua	4	NO	61	
47	3/02:16:00	Mexico/Monterrey-Sierra Madres	3	NO	60,61	
47	3/02:42:00	Suriname/Paramaribo-local mining	1	NO		Only daylight pass
48	3/04:19:00	Nicaragua/Volcanos-Coastline	2	NO	62	
48	3/04:22:00	Columbia/Jungle E of Cordillera	1	NO		Only daylight pass
49	3/06:06:00	Peru/Coastline-Pisco	1	NO	64	
49	3/06:07:00	Chile/Coastline-Tacna	2	NO	64	
50	3/07:03:00	Hawaii/betw Mauna Loa-Kea Army training site	1	NO		Only daylight pass
58	3/20:07:00	Mauritania/Dunes d' Alafia	1			
58	3/20:30:00	Kenya/Rift valley floor	2			
59	3/21:52:00	The Gambia/Georgetown-Marshes	3			
59	3/21:54:00	Mali/Sikasso-lowland areas	2			
59	3/22:08:00	Zaire/W. of Kalemi	1			
60	3/23:13:00	Mexico/Monterrey-Sierra Madres	3			
60	3/23:13:30	US/Ft Hood TX- Maneuver areas	1			
60	3/23:50:00	Bostwanna/Namibia Dsrt zambesi flood	3			Only daylight pass
61	4/00:50:00	Mexico/Baja cross-peninsula	2			
61	4/00:51:00	US/Ft Huachuca-Bisbee pit Mine	1			
61	4/00:52:00	Mexico/Chihuahua	7			
61	4/00:53:00	Mexico/Monterrey-Sierra Madres	11			
61	4/00:53:30	US/Ft Hood TX- Maneuver areas	3			
61	4/01:02:00	Cuba/Cienfuegos coast/lowlands	4			
61	4/01:03:15	Cuba/Guantanamo-lowlands	5			
61	4/01:26:00	Namibia/Namib des-mts coastal	8			
61	4/01:26:30	Namibia/Rehoboth-desert	6			
61	4/01:27:00	S.Africa/Botsw/Namibia-Molopo River	10			
61	4/01:27:30	Bostwanna/Kalahari Desert-pans	9			
62	4/02:54:00	Nicaragua/Coastline	1			
62	4/03:12:00	Namibia/Namib des-mts coastal	2			
64	4/06:15:00	Peru/Coastline-Pisco	2			
64	4/06:16:00	Chile/Coastline-Tacna	1			best pass

Figure 5. Earth Observation Chart.

Site Analysis Check Sheet

PERCENT CLOUD COVER SUN ANGLE

LANDFORM AND SLOPE ANGLE (Flat (0-15%)/Medium (15-45%)/Steep (>45%)

- PLAINS (percentage of target area)
- HILLS
- MOUNTAINS

VEGETATION (Percentage of target area)

- BARREN
- GRASSLAND
- BRUSH/SHRUB
- CULTIVATED
- FORESTED
  - DECIDUOUS
  - CONIFEROUS
  - MIXED (40-60% of either component)

SOILS

- GRAVELS
- SANDS
- SILTS
- CLAYS
- ORGANICS

GEOLOGY

- % SITE EXPOSED BEDROCK
- ROCK TYPE (SPECIFIC)
- ATTITUDE (STRIKE AND DIP 0-30/30-60/60-90)
- FAULTS/JOINTS (MAJOR FEATURE ONLY)

HYDROLOGY

- PATTERN
- DENSITY
- STREAM SIZE (0-18 METER OR >19 METERS)
- STANDING WATER (LAKES/MARSHES/SWAMPS - PERCENT AREA COVER)
- BANK CONDITIONS (GENTLE/STEEP; WET/DRY)

OBSTACLES

- NATURAL (AREA OR LINEAR)
- MANMADE (AREA OR LINEAR)

MAN MADE FEATURES/ SIZE REFERENCE (smallest ID item)

CROSS COUNTRY MOBILITY (FOOT/WHEEL/TRACK - NO GO/SLOW GO/GO)

- ORIENTATION AND SIZE

Figure 6. Earth Observation Checklist.

extremely high altitude a large amount of detail was observed. The checklist was used in orbit with success. The checklist was committed to memory and made ground observations easy to conduct.

Required Skills. According to Dr. Sullivan, a military observer would require geomorphology, pattern recognition, remote sensing, and photointerpretive skills to accomplish the mission.

Techniques. During the debriefing, Dr. Sullivan recommended some changes to shuttle flight procedure to increase the crew's awareness of future observation opportunities. First, she recommended that ground targets should be input into the Shuttle Portable Onboard Computer (SPOC) and into the shuttle's internal Com Site Manager (the SPOC will sound an audible tone to remind the astronaut 2 minutes or so before the target area is overflown; the Com Site Manager will do the same thing but transmit the tone over the internal shuttle communications loop). Both systems have been previously flown and are proven.

Second, ground target acquisition could be improved if either another crew member helped the observer spot upcoming sites or the astronaut used a set of visual cues from the target folder to find the approximate location of the target site. The further observable the feature is on the horizon, the better. Thus, high mountains, lakes or other major features that stand out would work best. The ONCs with readily discernable features to the immediate Northwest, West and Southwest of the target areas are good for this. Ideally these cuing features should be relatively near the site, but they should become visible within 2 minutes (600 kilometers) from time of closest approach to the shuttle.

Continual observation of an area with binoculars was found to be a limiting factor to target site study, due primarily to the binocular's fixed field of view. An observer must occasionally look at a ground target with the unaided eye to verify its relative location, and then identify a point on the ground to guide the binoculars to the detailed study. This procedure can be cumbersome, especially over unfamiliar territory, and it reduces the available study time over a site. To correct this, an observer must have either an optical device that will adjust the field of view (similar to a tele-zoom camera, i.e. zoom-binoculars or even SPADVOS) to put his target area in its proper perspective and to verify its location, or a device that will provide through-the-lens latitude and longitude information.

During the pre-flight training sessions, two methods of recording observation were proposed. The first involved recording comments into a cassette recorder as the site was viewed. The other method involved viewing the site and assimilating as much information as possible, then moving away from the window, and recording the observations without distraction. Both methods of recording observations of the target sites were tried in orbit. The best method for recording observations proved to be the second; to view the site, assimilate the data, and then record the information from memory into a mireocassette recorder or write it down once the site had passed from view. Although the other method of recording observations during the pass (talk-as-you-observe) was tried, it led to a loss of concentration in observing the target area. Both methods require further investigation.

Observation opportunities are itemized in figure 7. The following observations were recorded:

Target Number 38--Northwest Cape: The best viewing opportunity came over Northwestern Australia. The Northwest Cape Joint Facility located in the Exmouth Gulf in northwest Australia was observed. With hand held binoculars, Dr. Sullivan was able to discern building clusters and vehicle

Latitudes and longitudes represent the centers of mass of each ground target.

TGT NO	LAT	LON	LOCATION	TERRAIN	ACQUISITION DIFFICULTY
01	25 56N	100 51W	Mexico	High Desert	low
02	30 16N	115 22W	Mexico	Desert Scrub	low
03	25 55N	059 49E	Iran	Desert Coast	low
04	22 57N	082 54W	Cuba	Coastal Swamp	low
05	22 55N	059 02E	Oman	Desert	high
06	17 28N	049 04E	PDR of Yemen	Desert	high
07	20 05N	075 20W	Cuba	Coastal Plain	low
08	14 22S	074 44W	Peru	Coastal Mountains	low
09	18 35S	070 11W	Chile	Savannah	low
10	25 51S	015 36E	Namibia	Desert	low
11	18 36S	013 17E	Namibia	Desert	low
12	17 56S	024 55E	Botsw./Namibia	Desert	moderate
13	23 06S	024 54E	Botswanna	Desert	high
14	21 54N	017 09E	Chad	Desert	moderate
15	13 09N	013 54W	Senegal/Gambia	Marsh	moderate
16	22 51N	024 33E	Libya/Egypt	Desert	high
17	21 31N	011 38W	Mauritania	Desert	low
18	*** Deleted ***				
19	23 50S	017 50E	Namibia	Desert	high
20	05 50S	029 15E	Zaire	Plains	
21	01 24S	036 01E	Kenya/Tanzania	Savannah	low
22	01 28N	036 40E	Kenya/Tanzania	Savannah	low
23	07 20N	037 59E	Ethiopia	River Valley	low
24	02 59N	072 02W	Columbia	Jungle	high
25	*** Deleted ***				
26	11 38N	085 59W	Nicaragua	Volcanic Coast	low
27	28 47N	105 43W	Mexico	Chihuahua	low
28	23 30N	034 00E	Egypt	Desert	moderate
29	11 38N	005 59W	Mali	Lowlands	moderate
30	21 47N	055 53E	Saudia Arabia	Desert	high
31	27 00S	021 00E	South Africa	Desert	moderate
32	*** Deleted ***				
33	*** Deleted ***				
34	31 15N	097 45W	USA	Semi Arid	moderate
35	31 30N	110 30W	USA	Desert	moderate
36	19 40N	155 49W	USA	Volcanic Valley	low
37	21 50S	123 40E	Australia	Desert	high
38	21 53S	114 08E	Australia	Coastal Mtns	low

Figure 7. Ground Target Observation Opportunities.

parking areas. Road networks on the cape were quite evident due to their linearity and their contrasting composition to the reddish soil in the area. The seaward slope of the cape was characterized as being steep (>45%) and the leeward slope had a moderate (14-45%) slope. Along the southeastern coast of the Exmouth Gulf the dark fringy marsh/mangrove along the coast was determined to extend several miles inland. Further inland, beyond the mangrove the astronaut observed a region of salt pans which appeared to her to be dry and crossable, suitable for tracked and wheeled vehicles. The depth of the coastal water on the Indian Ocean side of the cape could not be determined, although a reef structure was indirectly determined due to the observation of breaking waves.

Target Number 07--Guantanamo, Cuba: The site was viewed only briefly. Other mission requirements over the site prevented a detailed observation.

Target Number 10--Namib Desert, Namibia: The target was easily identified. Operational commitments prevented a detailed observation.

Target Number 12--Namib Desert, Namibia: The geological feature called The Tadpole was visible during the pass. The terrain was characterized as being flat and gentle with isolated pockets of sand.

Target Number 17--Richat Structure, Mauritania: The Richat structure was highly visible and provided a good landmark reference. The surrounding area was observed to have large barchan sand dunes, estimated to be between 20 to 50 feet high. Exposed rock and areas covered by windblown sand could be clearly differentiated.

Target Number 24--Rio Guayabero Region, Columbia: The jungle site in Columbia was localized and spotted from orbit by the astronaut memorizing the configuration of a nearby river. Although the site was generally covered with clouds, the river (due to convection currents) was free of clouds and could be readily identified. This was confirmed by using the sunglint technique. Sand bars within the river could also be identified. The dense jungle canopy prohibited further analysis of the ground target.

Target Number 23--River valley, Ethiopia: The look angle was not the best for observation of soil conditions in the Great Rift Valley. Dr. Sullivan used the sunglint technique to discover what she called "extra pockets of water," i.e. more surface water than was indicated on the ONCs provided to her. Although she could determine that the area was heavily faulted, she had no precise sense of scale. She was able to determine sizes of objects $\pm$ 100 feet in length.

Target Number 35--Fort Huachuca, Arizona: The site was viewed without binoculars. The altitude of the shuttle allowed for a window observation of 1 degree on either side of the actual ground track. This site tested the limits of human observation at extreme angles. Though the weather over the site and the lighting conditions were adequate, the site (1.5 degrees north of the ground track) was too far north for an accurate appraisal.

Other Observations: Several sites were not observed during the flight. A listing of observed sites and reasons for the non-observed sites are located in figure 8. Several sites went unobserved due to cloud cover. Other sites were too far out on the shuttle's horizon to be fully observed. As expected, several desert ground targets were also difficult to locate.

Ground Targets:

Ground Targets Viewed	08
Ground Targets Not Viewed	
Searched for	03
Not Searched for	23
Ground targets Deleted	04
	38

Ground targets Viewed:

No. 38	Australia- good view
No. 07	Guantanamo- seen, HST deploy/No data
No. 10	Namib coastal- good sun angle/relief- HST deploy/no data
No. 12	Namib Interior- good view
No. 17	Richat Structure- good view
No. 23	Rift valley- poor angle
No. 24	Columbia- Popcorn clouds degraded view
No. 35	Fort Huachuca- region seen bad angle/no data

Ground targets searched for but not viewed:

No. 11	Northern Namib site- Not picked up well/cloud cover
No. 26	nicaragua- weather obscured view
NO. 34	Ft Hood- weather obscured view

Figure 8. Ground Target View Opportunities.

Some desert sites were particularly difficult to locate due to the lack of observable featuıes or visual cues in the area. Despite availability of an ONC, an oblique photo, and a clear sky, two deep desert sites, one in Yemen (Target number 06) and the other in southeastern Saudi Arabia (target number 30) were searched for but never identified. This indicates, as Dr. Sullivan stated, that to be observed desert sites must have either long lead-in features to orient the observer or large scale regional photos or maps available for study. They should be studied intensely over long periods of time; be studied via through-the-lens system, which will update the LAT/LONG you are viewing or be cued from the SPOC. A combination of any of the above would be helpful.

Percentage of Cloud Cover: No data was gathered regarding the percentage of cloud cover over a target site. Dr. Sullivan still believes that although this aspect of the experiment was not accomplished, percent of cloud cover over a site could still be determined.

Landform and Slope Angle Determination: As part of the terrain analysis, Dr. Sullivan was asked to determine slope characteristics of hilly and mountainous terrain. She reported that slopes would be difficult, but not impossible, to characterize. Dr. Sullivan believes that with a low (and preferably known) sun angle, slope determination could be accomplished. The necessary information can be obtained from a NASA ephemeris and fed to the shuttle and not determined from orbit as that would over burden the space observer. With the known sun angles, the scales and characteristics can then be computed. The best sun angles for determining relief features is between 15 to 20 and 50 to 60 degrees.

Slope determination cannot be accomplished with a nadir or near nadir sun as the wash of bright light tends to make even large scale objects appear flattened. This problem may be overcome by prior knowledge/familiarity with the terrain, and knowledge of altitude and lengths of certain terrain features as a reference. The ONC's would be a good source for this information.

Vegetation Analysis. Part of the selection process of ground targets included a variety of vegetation. This ranged from the lush jungles of Columbia to savannahs in Eastern Africa to the deserts of the Middle East. Dr. Sullivan discovered that from a 310 nautical mile altitude, determination of vegetation differentiation is limited. Differentiating between deciduous and coniferous trees is possible only during seasonal changes. However, differentiation between cultivated, barren, covered, and scrub vegetation can be accomplished. To enhance the accuracies of the observations, one is required to have prior knowledge of the area including its humidity characteristics.

Soils. Determining grain size proved to be difficult. Differentiation could not be made between sands, silts, clays and organics by direct observation. Boulder fields or quarry rocks however, were visible. Differentiation between soil conditions would be possible at lower altitudes. This lack of data could however be offset by a-priori knowledge of the ground target coupled with the knowledge of where each soil condition is likely to occur. From the high orbit of the shuttle on this mission, determination of sands and silts was not possible unless they had accumulated into visible structures such as dunes.

Hydrology. Observation of areas of standing water also provided significant data. Dr. Sullivan was asked to study standing bodies of water as well as rivers. From a 330 nautical mile altitude, she was able to discern rivers features as small as 18 meters in width. The "sunglint" method of determining the extent of standing water proved to be effective during the flight. The technique involves studying the "glint," or reflected light from the sun as reflected off the surface of the water. During the debriefing, Dr. Sullivan noted that the extent of the standing water and marshes are characteristically greater than what could otherwise be visualized. At some sites (target number 22) standing water appeared to cover a surface twice as large as was depicted on the ONC's and in areas not indicated.

The sun glint technique has a high degree of military value in the planning of tactical operations. Using this technique, an observer could accurately determine the extent of standing water in relation to a standard topographical map. The extent of flooding, increases or decreases in the areas of marsh, mangrove or swamplands could be accurately determined, differences between topographical maps and actual ground conditions could be identified, and the information then sent to ground commanders planning their operations.

Specific water depths were difficult for Dr. Sullivan to determine on this flight. Some underwater features could be indirectly identified, as in the case of the Northwest Cape of Australia by viewing breakers of the coast. These features were readily identified. Other underwater features, such as fletches and shoals, could be observed, but required clear, shallow water. Turbid water makes direct observation of underwater features impossible.

Dr. Sullivan was also asked to determine gap sizes and bank conditions. She discovered that gaps as small as 18 meters were detectable from the shuttle's 310 nautical mile orbit. Gyrostabilized binoculars provided the most stable optics to view these small gaps and were key for this type of observation. While observing the gaps, she noted that wet or dry bank conditions of these gaps may also be determined by comparing tonal variations in the exposed soils.

Obstacle Determination. This was not accomplished during the mission due to astronaut unfamiliarity.

Cross Country Mobility Determination. The cross country mobility predictions was partially accomplished at one ground target, number 38 the Northwest Cape Joint Facility.

Discussion. All the elements that comprise a terrain analysis are clearly possible to accomplish from space. To be effective in accomplishing this task, the astronaut-observer must have finely developed skills in the areas of terrain analysis, geomorphology, pattern recognition, remote sensing, and photointerpretation.

Due to time available to view each site, site familiarity by the observer is crucial; there is no substitute for a lack of information about the ground target. A lack of familiarity leads to excessive search and acquisition time that in turn reduces available viewing time over the site.

No developmental changes are anticipated for the checklist.

As an alternative method of making voice notes of each site, Dr. Sullivan suggested that an observer could leave a voice recorder on during a pass and make a number of verbal notes; a few words or key phrases that would serve to jog the observer's memory after the pass. In addition to making recorded voice notes, electronic still images of the site played back after a site pass would serve to aid the observer even more, bringing more to mind than any recorded notes could.

Regardless of imagery experience, the novice astronaut will require a few revolutions to orient the astronaut to viewing from space. A year of intensive scrutiny of shuttle imagery will familiarize an astronaut sufficiently to offset the advantage of having a previous space flight.

Observation. Dr. Sullivan noted during the debriefing that the quality of detail possible in any observation will vary due to the lighting levels and number of repeat passes over a site. Improvements of future target site observations within the available time can be achieved by several means. (1)Information regarding each target could be pre-recorded and listened to as an observer acquired a new target. (2)Another method would be to use electronic still images. Once developed, a Charged-Couple Device (CCD) still camera could also be of benefit to the observer. Assuming the capability of playback on-orbit, the observer could review an electronic still image taken over the site. This capability would tend to bring more to mind for conducting a terrain analysis of an area than any recorded notes made during a pass. Such a camera would also be of tactical benefit to ground forces should the capability to take, store, and transmit digital images from the shuttle to ground forces be developed.

Discussion. The evaluation of techniques and criteria required to conduct terrain analysis from orbit were explored using ground sites with terrain of various types. Investigations need to continue into the utility of color and polarizing filters used by the observer when viewing a target site. Also the techniques for the determination of soil color need to be refined.

Soil color is one of several facets of terrain analysis which provides clues to composition and relative soil moisture content on the surface. These clues in turn can indicate relative drainage and trafficability for ground forces. If soil color studies are to be continued from orbit an index of possible soil types arranged by color composition must be developed and tested on an experimental basis on subsequent space shuttle flights.

The results of STS-31 indicate the feasibility of conducting realtime terrain analysis from low Earth orbit. The next step in the experiment would be to test how these observations could be used to influence realtime military operations. This would require the experiment continue to its next phase and utilize a trained military observer on orbit. The military observer would have both the technical knowledge to assess the terrain and the military knowledge to understand how ground operations can be affected or enhanced by it and report that information to ground commanders.

CONCLUSION

Techniques for assessing terrain from orbit were developed. As a result, all the components which comprise a terrain analysis can be conducted in orbit.

Though time over site is a limiting factor, the shuttle offers a unique perspective of the terrain. Throughout the experiment it became evident that the space-based human observer can play a key role in analyzing the terrain.

Of special significance is the human value-added aspect of instant comparison and analysis. The comparisons of standing water (site #23 viewed versus mapped) illustrates this point.

Further experimentation into terrain analysis area needs to be continued. Ground targets need to be viewed by an expert military observer. Unlike the current astronaut corps, this person would be able to combine both military and science skills necessary to develop mobility predictions.

Limitations of a detailed analysis have to do with lack of time over a target site. This problem can be solved by developing an electronic camera to take still images of a site for playback on orbit. The camera should be equipped with a device to indicate the latitude/longitude of the ground targets.